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# Spatial and Seasonal Trend of Trace Metals and Ecological Risk Assessment along Kanyakumari Coastal Sediments, Southern India

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**ABSTRACT:** The concentration of selected trace metals (Fe, Cd, Cu, Pb, and Zn) in 30 surface sediments were measured using Atomic Absorption Spectrometer to investigate the spatial and seasonal variations of trace metals along Kanyakumari coast, India. To assess the environmental risk of trace metals, enrichment factor, geo-accumulation index, pollution load index, and ecological risk index have been calculated. According to the pollution load index and geo-accumulation index (Igeo) values, Kanyakumari coastal sediments were unpolluted by Fe, Cu, Pb, and Zn, whereas moderately polluted by Cd with low to moderate ecological risk. The existence of the high hydrodynamic condition during the southwest monsoon is more favorable to the transport of sediments and enhance the accumulation of metals, whereas during the northeast monsoon the accumulation of metals is less. The baseline data for spatial distribution and seasonal variation of trace metals and their controlling factors found in this study will be useful for pollution monitoring program along the Kanyakumari coast.

**Keywords:** hydrodynamics, Kanyakumari coast, sediment texture size, TOC, trace metals.

## INTRODUCTION

Trace metal pollution in the marine environment is of great concern around the world (Mashal *et al*., 2014; Guevara *et al*., 2005; Allen, 1995) because of their toxic effects, long-term persistence, and bioaccumulation characteristics (Al-Taani *et al*., 2015; Moosavian *et al*., 2014; Lafabrie *et al*., 2007; Sin *et al*., 2001). Metals enter into the marine environment from geogenic or anthropogenic sources (Al-Taani *et al*., 2015, 2014, 2012; Bai *et al*., 2011). Natural sources are mainly added from weathering of soil and rock, erosion, forest fires, and volcanic eruptions and anthropogenic sources are added from urban and industrial discharge, mining and refining, and agricultural waste discharged (Shang *et al*., 2015).

Some of the metals are nutritionally essential (Fe, Mn, Co, Cu and Zn) with low concentrations. Although, some sediments are higher in trace metal concentration (e.g., mercury, lead, and cadmium), which are potentially toxic to the marine ecosystem (Nagajyoti *et al*., 2010). These metals enter estuaries and coastal waters from various sources such as residential wastewater, drainage dust deposition, industrial sources, storm water, and agricultural runoff (Zhao *et al*., 2012; Yang *et al*., 2012).

Sediment represents the pollutants in coastal and estuarine systems that are

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impacted by anthropogenic activities (Veerasingam *et al*., 2014). The accumulation of sediments trace metals were mobilized by the natural process (Celino *et al*., 2008) in the aquatic environment, due to sediment texture, the physicochemical condition of the water, and chemical characteristics of the metal. The finer particles would be trapped in coastal environments due to the decomposition of organic matter and they are transported by the hydrodynamic energy (Williamson and Wilcock, 1994). Hydrodynamic forcing plays an important role on sedimentation and their trace metal distribution. Particularly, tide-induced sediments resuspension and remobilization affect the trace metal cycles (Strady *et al*., 2011).

Bottom settled surface sediment samples have been used for accurate assessment of trace metal pollution (Du Laing *et al*., 2009; Alyazichi *et al*., 2015) which absorb persistent and higher concentration of toxic level than water (Arias Almeida and Ramirez Restrepo, 2009). Characterizing bottom sediment quality and metals contamination in coastal areas is an important management tool for assessing coastal ecosystem health.

In this study, considerable attention has been given to assess the ecological risk in the Kanyakumari coastal environment. Gulf of Mannar (GoM) is one among the important natural biosphere reservoirs in south Asia, which is located in the northeast of the study area. The coastal area has also stressed by Koodankulam nuclear power plant, Pazhayar, Hanuman Nadhi, and Namiyar River discharges. Therefore, the ecological risk assessment for the Kanyakumari coast is important to assess the possible influence of natural and anthropogenic activities.

In recent year, ecological risk assessment of toxic metals has attracted more considerable public attentions in the aquatic environment (Dhanakumar *et al*., 2013; Venkatramanan *et al*., 2013; Varol and Sen, 2012; Segura *et al*., 2006; Lim *et al*., 2013). Many researchers have studied the trace metal contamination in the west coast of India (Volvoikar and Nayak, 2015; Fernandes and Nayak, 2014; Fernandes *et al*., 2011; Basha *et al*., 2010; Alagarsamy, 2006) and east of India (Santhiya *et al*., 2011; Selvaraj *et al*., 2004; Suresh Gandhi and Raja, 2014; Nobi *et al*., 2010; Selvaraj *et al*., 2004). However, no information is available about ecological risk assessment in this coastal sediment. Such an investigation is necessary for the quantitative and qualitative information on the pollution level and its impacts on the marine environment. Therefore, the present study investigates spatial and seasonal distribution of trace metal concentration and its ecological risk assessment in the surface sediments along Kanyakumari coast.

## MATERIALS AND METHODS

### Study Area

Kanyakumari coast, also known as Cape Cameron, is located in the southernmost part of India (Fig. 1) and occupies 68 km total length of the coastal area (Natesan and Parthasarathy, 2010) surrounded by Colachal port and fishing harbor (Chinna Muttom harbour).

The study area has a small estuary at Manakudy formed by the confluence of river Pazhayar in between east and west Manakudy villages, which covers a diverse range of features including beach terraces, low cliffs, sandy beaches, rocky shores, river, and estuarine inputs such as Pazhayar River. The annual gross sediment transport rate along the Kanyakumari coast is 190.87 $x10^3$ unit, where the southerly movement of sediment is deposited in a beach environment during the SW monsoon (Saravanan and Chandrasekar, 2010).

Gulf of Mannar (GoM) is located in the southeast coast of India and extends from Rameswaram Island in the north to Kanyakumari in the south (Diraviya Raj *et*

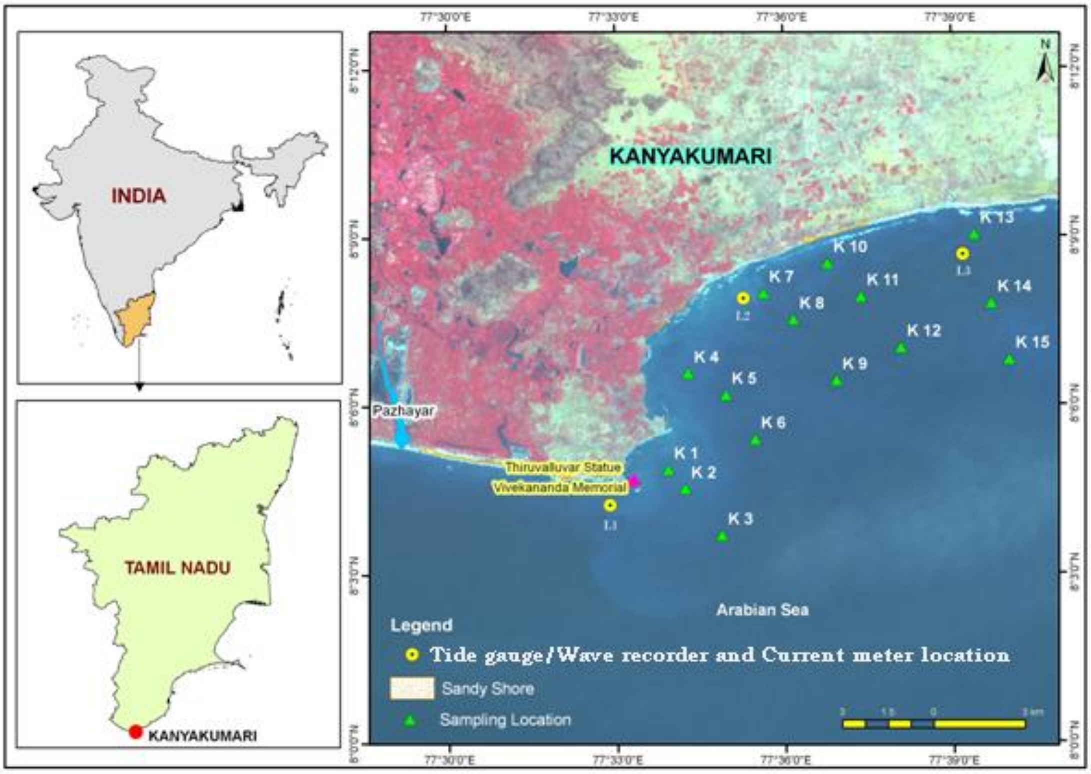


**Fig. 1. The study area map shows the sampling locations**

*al*., 2015). The ecologically sensitive area is located in the northern part of the study area and comprises 21 Islands with estuaries, mudflats, beaches, Seagrass, Coral reefs, and mangroves. The special intention of the study area is enriched with placer deposits, including significant amounts of monazite, ilmenite, rutile, and garnet and a small amount of zircon and illimenite and also it is a very famous pilgrimage and tourist center.

## Sample Collection and Analytical Techniques

Fifteen surface sediment samples were collected along the Kanyakumari coast from the Southern tip of near Chettikulam in 5, 15, and 25 m water depth during January 2011 (Northeast monsoon) and August 2011 (Southwest monsoon) using a Peterson grab sampler. Single beam echosounder (Odam hydrotrac) was used to determine the water depths and geographic coordinates of the sampling points were identified by DGPS (Differential Global Positioning system). Samples were taken from the central part of the grab sampler and sub-sampled carefully in acetone rinsed plastic/polyethylene bags. All samples were stored in an icebox and transported to the laboratory for further analysis.

In the laboratory, 50 mg of sediment sample was taken for digestion (3 ml hydrofluoric acid and 9 ml nitric acid) using PTFE Teflon bombs in a closed suitable microwave digestion system. The procedure continued up to 20 minutes at 20-220˚C. The obtained suspension was filtered by Whatman filter paper, and collected in polypropylene tubes. The residues were finally used to analyze the trace metal analysis by Perkin Elmer Analyst 200 Atomic Absorption Spectrometer (AAS). The AAS detection limits were calculated as $3\sigma/S$ ($\sigma$ is the standard deviation of the blank signal, and $S$ is the sensitivity). The instrument was standardized using standard solutions and an internal standard was added to the samples. Standard reference material MESS-3 contains reference information about the concentration ranges of sediment samples and it ensures the quality control and accuracy of the analysis. All the results have shown good agreement with the certified data.

## RESULTS AND DISCUSSION

### Sediment Texture and Total Organic Carbon

The sedimentary process along east and west coast of India are significantly different due to the sedimentary load discharged by the peninsular river. The large sedimentary discharge from the east coast of India is relatively high compared to the west coast sediment fluxes. The sediment texture composition was assessed as the percentage of sand, silt, and clay, which are controlled by the physical transportation of sediments, including sediment aggregation, deposition, and tidal circulation (Wai *et al*., 2004). In the study area, sediment texture was fairly broad (Fig. 2).

The ranges of sand, silt, and clay during NE monsoon are 40.58-98.33%, 1.22-56.76%, and 0.44–2.66% with mean values of 78.12%, 20.70% and 1.16%, respectively, whereas during the SW monsoon, sand, silt, and clay values are ranged as 5.55-98.32%, 1.22-88.01%, and 0.22-11.61% with mean values of 32.40%, 62.74%, and 4.85%, respectively. The organic carbon is rich in sediments and

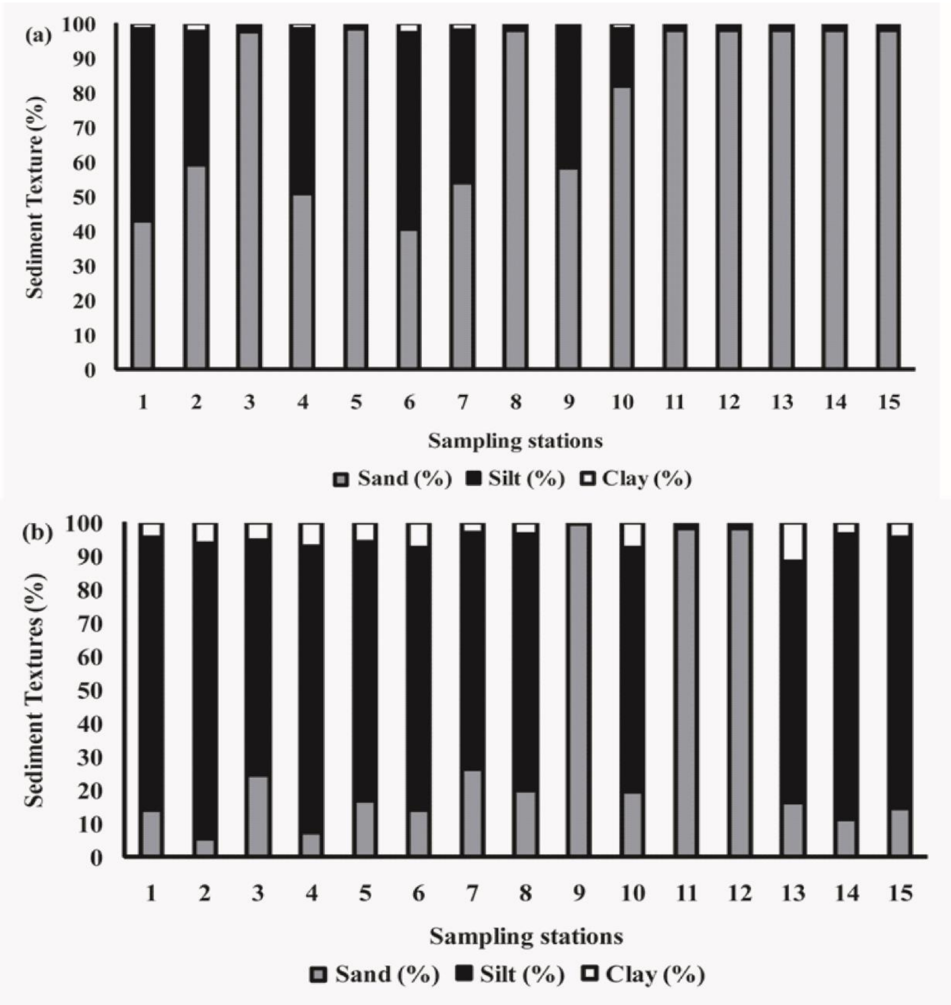


**Fig. 2. Distribution of sediment texture (sand, silt and clay) during (a) NE monsoon and (b) SW monsoon**

predominant in clay (Robin *et al*., 2012). Total organic carbons in sediment were ranged from 1.234 to 3.781 mg/g and 1.749 to 10.232 mg/g with mean values of 2.554 and 6.076 mg/g for NE and SW monsoon seasons, respectively (Fig. 3a).

The maximum value of TOC (10.232 mg/g) was observed during Southwest monsoon season at sampling location K 13 (5m depth). The relationship between TOC and sediment texture is widely well studied by several researchers (Secrieru and Oaie, 2009; Anitha and Sugirtha, 2014). The relationship between TOC and sediment texture was found using Pearson's correlation analysis (Fig. 3b-e). TOC is positively correlated ($R^2$=0.658 and 0.704) with mud (silt + clay) and negatively correlated with sand (-0.658 and -0.703) in both NE and SW monsoons due to the presence of fine particles, which are able to trap more total organic carbon (Percival *et al*., 2000). Muller and Suess (1979) have also observed similar correlation maybe due to the decomposition of plankton.

Sediments are excellent indicators of pollution and the eutrophication rate (Folger, 1972; EPA, 2002), whereas the total organic carbon is a most important factor to control the heavy metals in sediments, which has a high specific storage capacity (Zarei *et al*., 2013).

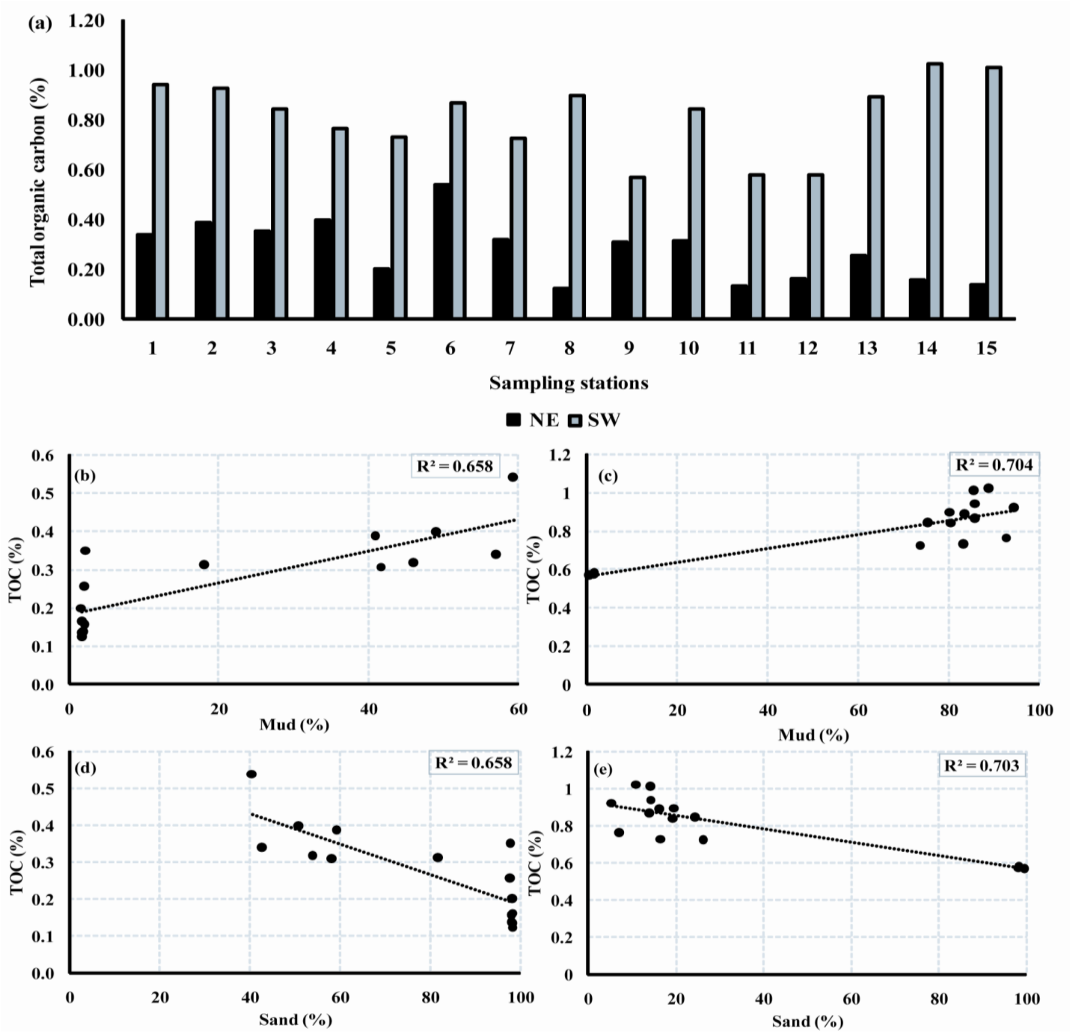


**Fig. 3. Spatial distribution of Total Organic Carbon (TOC) and their relationship with the percentage of sediment textures. (a) indicates TOC, (b-c) indicates the TOC correlated with mud (silt+ clay) and (d-e) indicates the TOC correlated with sand during NE and SW monsoon respectively.**

## Distribution of Trace Metal Contaminations

The spatial distribution of trace metals in coastal and marine environments around the world contaminated by varieties of sources, such as natural and anthropogenic discharges, binds to the seafloor (Fu and Wang, 2011; Vinith Kumar *et al*., 1999). In the Indian Ocean, the metal pollution sources are derived from riverine discharges. Based on the long-term measurements (Alagarsamy and Zhang, 2010), it is found that the Arabian Sea has a higher concentration of trace metals than the Bay of Bengal. The spatial distribution of trace metals (Fe, Cd, Cu, Pb and Zn) determined in the study area are shown in Figure 4.

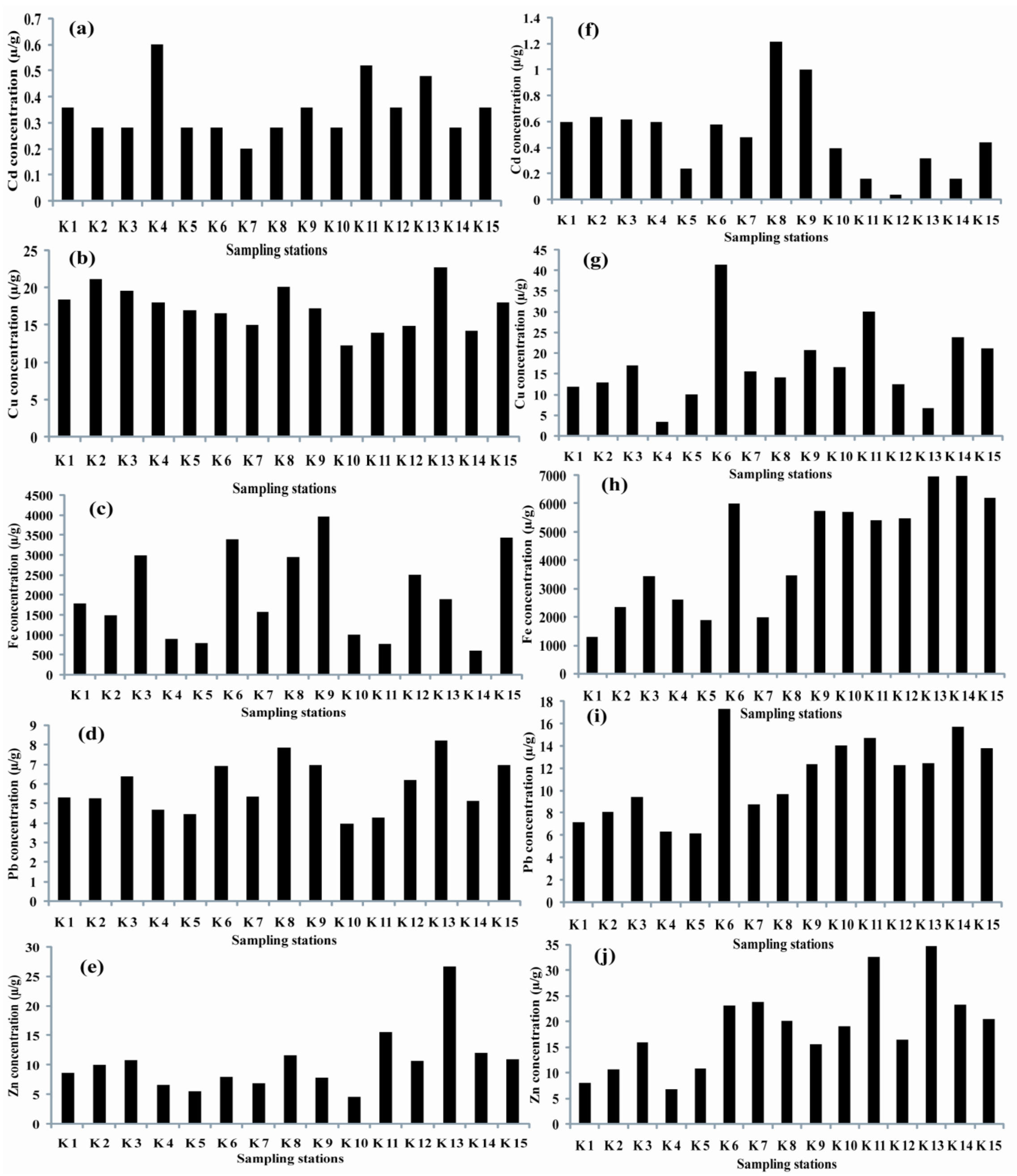


**Fig. 4. Trace metal concentration in surface sediments during (a-e) northeast monsoon and (f-j) southwest monsoon.**

The measured values of Fe, Cd, Cu, Pb, and Zn in sediments range between 614.8-3980.4, 0.2-0.6, 12.32-22.76, 4-8.24, and 4.6-26.8 µg/g, respectively, during NE monsoon, whereas those values for SW monsoon vary as 1307-6992, 0.16-2.08, 3.58-41.4, 6.12-17.32, and 6.2-34.64 µg/g, respectively. The average values of trace metals along Kanyakumari coastal sediments were ranged as Fe > Cu > Zn > Pb > Cd in NE monsoon, while in SW monsoon those values were ranged as Fe > Zn > Cu > Pb > Cd.

The abundance of the high amount of metal contamination in the sediments has been observed during the SW monsoon period. Seasonal currents approach to mobilize the contaminated sediments towards the northeast in SW monsoon season. Herewith, the Indian coastal current circulation pattern carries the pollutions from the north of Arabian Sea with an energetic hydrodynamic and wave conditions. The monsoon currents reflect the accumulation of trace metals from remote sources of Arabian Sea.

According to the previous studies (Table 1), the level of trace metal pollution varies greatly from coast to coast around the world. Among the coastal sediments, Kanyakumari coastal sediments have a great concern as chemically low metal pollution in a healthy ecosystem.

Iron is found as an abundant element in the continental crust; the average abundance of Fe in the earth's crust is 47,000 µg/g. The concentration of Fe varied from 1307.6 to 6992.0 µg/g and 614.8 to 3980.4 µg/g with a mean value of 4370.59 and 2011.73 µg/g during SW and NW, respectively. It is less than the mean concentration of a background level. The iron associated with the carbonate fraction is sorbed as Ca in the calcite crystals (Mansour *et al*., 2013). The mean

**Table 1. Summary of comparison of trace metal concentrations (µg/g) of Kanyakumari sediments with the International and National coastal sediments**

| Study area | Cd | Cu | Fe | Pb | Zn | References |
|---|---|---|---|---|---|---|
| Tarut Island, Saudi Arabia | 0.1-3.5 | 1.4- 21 | 599-12,924 | 5.2- 471 | 5.3- 51.9 | Youssef *et al*. (2015) |
| Shungtaizi Estuary, Bohai Sea of China | - | 2.11-30.58 | - | 10.12-24.62 | 14.76-01.58 | Yang *et al*. (2015) |
| Bohai Bay, China | 0- 0.98 | 7.2- 63 | - | 4.3- 138 | 58- 332 | Zhou *et al*. (2014) |
| Oman | 1.8 | 13.6 | - | 10.5 | - | Al-Husain *et al*. (2014) |
| Red Sea (Egypt) | 2.3 | 17.8 | 1796 | 38.5 | 42.2 | Madkour *et al*. (2012) |
| Sauipe Estuary, Brazil | - | 14.15 | - | 8.26 | 1.05 | Reitermajer *et al*. (2011) |
| Yangtze River, China | 0.40 | 44.75 | - | 39.32 | 120.42 | Yi *et al*. (2011) |
| Visakapatnam, India | 3.6 | 7.2 | - | 19.9 | 27.0 | Sarma *et al*. (1996) |
| Chennai, India | 0.52 | 3.71 | - | 2.49 | 10.08 | Veerasingam *et al*. (2012) |
| Cochin back water | 2.1± 0.76 | - | - | 43.34± 8.63 | - | Robin *et al*. (2012) |
| Thengapattanam Estuary, India | - | 3- 18.57 | - | - | 7.38 | Anitha and Kumar (2014) |
| Kanyakumari, India (NE monsoon) | 0.35 | 17.32 | 2011.73 | 5.89 | 10.47 | **Present study** |
| Kanyakumari, India (SW monsoon) | 0.50 | 17.27 | 4370.59 | 11.23 | 18.76 | **Present study** |

concentration of Cd at 0.347 µg/g (NE) and 0.50µg/g (SW) is reliable with previously reported level of 0.52 µg/g (James Balagan Anand and Mary Jelastin Kala, 2014). Similarly, Palanichamy and Rajendran (2000) have observed the moderate level of Cd ranged between 0.4 to 1.0 µg/g along Kanyakumari coast due to heavily industrialized areas of the SE Coast of India (Jonathan and Ram Mohan, 2003). In Sikka and Vadinar, Gulf of Kachchh region showed the agricultural discharges are responsible for increasing Cd contamination (Chakraborty *et al*., 2014).

The abundance of Pb in the earth's crust is 20 µg/g. The distributions of Pb elements in the present study ranged from 6.12-17.32 µg/g and 4.0-8.24 µg/g in the coastal transect of SW and NE monsoon respectively. Compared to the earth's crust value, the present observation of Pb showed systematically lower concentrations in all sampling stations. The average concentration of 11.53 µg/g has been found in SW monsoon, which is considerably higher than NE monsoon (5.89 µg/g) period. The increased concentration of metals in surface sediments is more pronounced and energetic in SW monsoon season maybe due to the strong convergence of high wave energy.

The sediment transportation and their degree of sorting are also likely to be more intensive in south-west monsoon period (Saravanan *et al*., 2011). The refraction pattern and its role in the redistribution of sediments are discussed by many authors (Saravanan and Chandrasekar, 2015; Chandrasekar *et al*., 2001; Angusamy *et al*., 1998). These decreasing trends of seasonal concentration of trace metals are probably caused by the ''self-purification'' process (Cukrov *et al*., 2008). The average concentration of Pb in the Indian river (Dekov *et al*., 1999) sediments have been reported as ~14 µg/g and their environmental effects have been well recognized by Landrigan and Todd (1994).

The highest concentration of Cu (22.76 and 41.4 µg/g) was measured with an average range of 17.3 µg/g and 17.2 µg/g for NE and SW monsoon seasons. The seasonal variation of mean Cu in the coastal sediment is negligible. A natural distribution of zinc in the earth's crust ranges between 0.0005% and 0.02%. Hamed *et al*. (2009) reported that Zn can be precipitated as ZnCO. The average concentration of Zn clearly showed that organic waste water discharging from Manakudi estuary.

Table 2 and 3 show the relationship between the sediment textures, TOC, and trace metals. Clayey sediments show a significant positive correlation with TOC, however, TOC did not play a vital role in metal sorption. The significant positive correlation obtained between Pb-Fe (0.77-0.90) and Pb-Cu (0.62-0.77) and other elements are poorly correlated within the trace elements. In the earlier studies, significant positive correlations between Pb with Fe, Cu, and Zn have also been found by Kumar *et al*. (2015) in GoK (Gulf of Kachchh), which shows that metals are common anthropogenic activities.

The seasonal fluctuation of metal during the NE monsoon season was comparatively weaker than SW monsoon. Therefore, sources of pollution are high in SW monsoon due to the SW monsoon currents carrying metals by the change of hydrodynamic effects. The convergence to divergence beach morphology in different periods has also been attributed to the seasonal changes in the quantum of sediment movement (Hanamgond, 1993).

**Table 2. Pearson correlation matrix for the sediment texture, TOC and trace metal in surface sediments collected during NE monsoon**

| | Sand | Silt | Clay | TOC | Cd | Cu | Fe | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|
| **Sand** | 1.00 | | | | | | | | |
| **Silt** | -1.00 | 1.00 | | | | | | | |
| **Clay** | -0.88 | 0.87 | 1.00 | | | | | | |
| **TOC** | -0.88 | **0.87** | **0.95** | 1.00 | | | | | |
| **Cd** | 0.02 | -0.02 | -0.18 | -0.08 | 1.00 | | | | |
| **Cu** | -0.03 | 0.03 | -0.01 | -0.05 | 0.15 | 1.00 | | | |
| **Fe** | -0.10 | 0.11 | 0.04 | 0.06 | -0.20 | 0.32 | 1.00 | | |
| **Pb** | 0.13 | -0.13 | -0.20 | -0.18 | -0.04 | **0.62** | | 1.00 | |
| **Zn** | 0.44 | -0.44 | -0.45 | -0.49 | 0.40 | 0.49 | 0.02 | 0.53 | 1.00 |

**Table 3. Pearson correlation matrix for the sediment texture, TOC and trace metal in surface sediments collected during SW monsoon**

| | Sand | Silt | Clay | TOC | Cd | Cu | Fe | Pb | Zn |
|---|---|---|---|---|---|---|---|---|---|
| **Sand** | 1.00 | | | | | | | | |
| **Silt** | -1.00 | 1.00 | | | | | | | |
| **Clay** | -0.76 | 0.72 | 1.00 | | | | | | |
| **TOC** | -0.76 | **0.73** | **0.96** | 1.00 | | | | | |
| **Cd** | -0.14 | 0.16 | -0.02 | 0.11 | 1.00 | | | | |
| **Cu** | 0.22 | -0.21 | -0.27 | -0.25 | -0.04 | 1.00 | | | |
| **Fe** | 0.29 | -0.31 | 0.01 | -0.09 | -0.28 | 0.47 | 1.00 | | |
| **Pb** | 0.28 | -0.29 | -0.10 | -0.16 | -0.26 | **0.77** | **0.90** | 1.00 | |
| **Zn** | 0.23 | -0.25 | 0.05 | -0.11 | -0.28 | 0.42 | **0.66** | **0.67** | 1.00 |

## Trace Metals Risk Assessment

To study the risk of trace metal contaminations in sediments, the degree of metal enrichment was assessed by enrichment factor (EF), geo-accumulation index (Igeo), pollution load intensity (PLI), and ecological risk index to estimate the sediment contamination by the selected trace metals.

### Enrichment Factor (EF)

The enrichment factor (EF) is an effective method to indicate the sources of metal contamination from natural geochemical background to anthropogenic inputs (Zhang and Liu, 2002). The EF is calculated in degrees of metal sedimentation (Lee *et al.*, 1998; Kersten and Smedes, 2002; Woitke *et al.*, 2003) by the following equation:

$$EF = (Metal/Fe)_{sample} / (Metal/Fe)_{background} \quad (1)$$

where, $(Metal/Fe)_{sample}$ and $(Metal/Fe)_{background}$ are the metal concentration in relation to Fe in the sediment samples and background values. An anthropogenic and atmospheric loading is the primary source of cadmium in the marine environment (Kennish, 1996). EF values between 0.5 and 1.5 suggest natural weathering processes (Zhang and Liu, 2002) and above 1.5 suggest the anthropogenic source. Based on the above-recommended values, it is evident that the Kanyakumari coastal sediments were contaminated by both lithogenic and anthropogenic sources.

### Geo-accumulation Index ($I_{geo}$)

The geo-accumulation index (Igeo) was proposed by Muller (1979) and is used to evaluate the metal pollution by comparing the measured sample concentrations with pre-industrial levels. The Igeo is defined by the following expression:

$$I_{geo} = \log_2\left(\frac{C_n}{1.5B_n}\right) \quad (2)$$

where $C_n$ is the measured metal concentration and $B_n$ is the background metal value. The factor 1.5 is used for the possible variations of the background data due to lithological variations (Veerasingam *et al*., 2014). According to Salehi *et al.* (2014), the following classifications are introduced: ≤0.42: unpolluted, 0.42- 1.42: low polluted, 1.42- 3.42: moderately polluted, 3.42- 4.42 strongly polluted, >4.42: extremely polluted. In contrast with above categories, Igeo calculated for Cd, Cu, Fe, Pb, and Zn implies that Cd in the Kanyakumari coastal environment is low polluted and moderately polluted with a mean of 1.15 and 1.49 during NE and SW monsoons. Whereas, Cu, Fe, Pb, and Zn indicate the unpolluted sediments (Fig. 5).

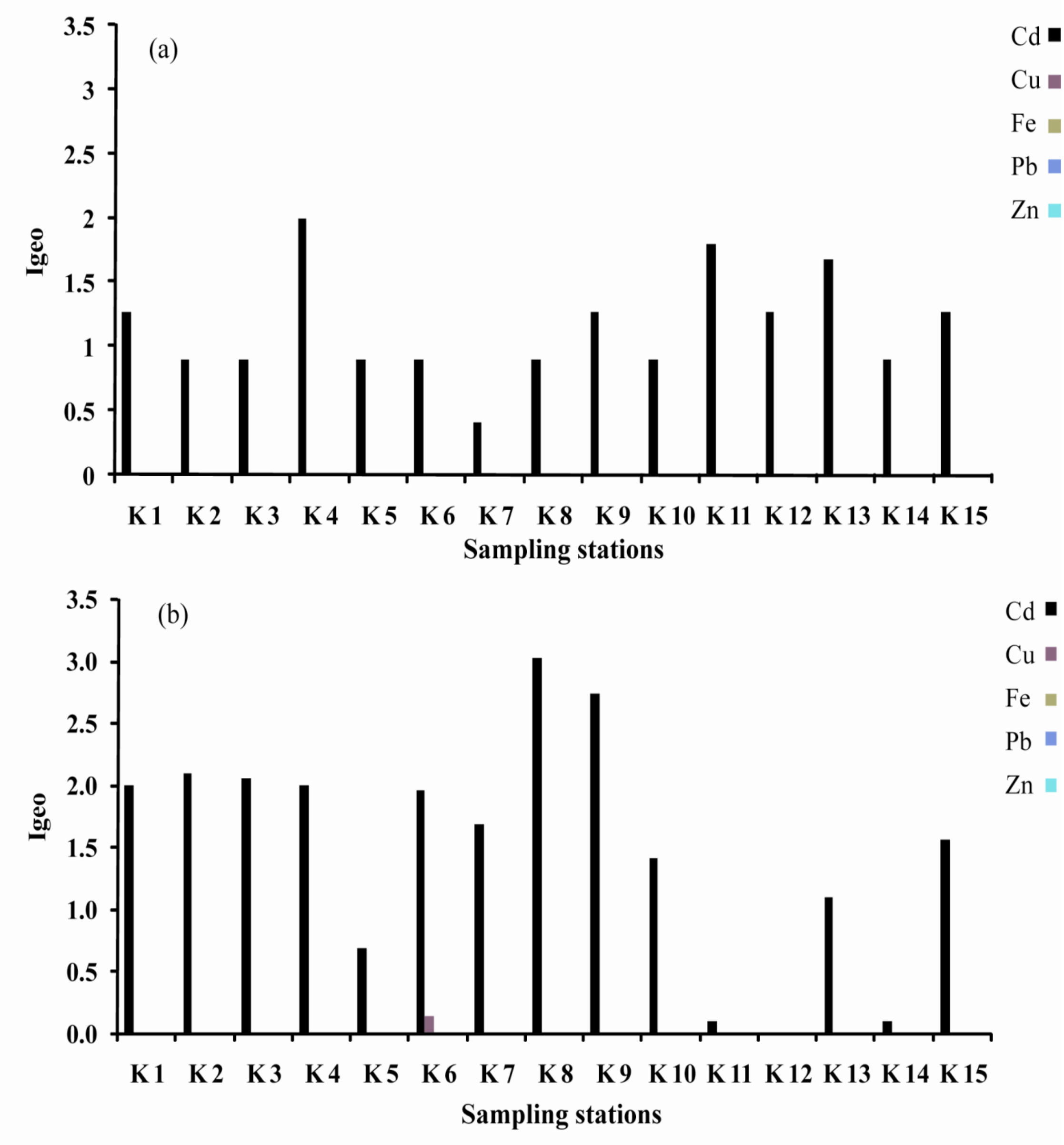


**Fig. 5. Showing the level of Geo accumulation index. (a) and (b) indicates the NE and SW monsoon respectively**

## Pollution Load Index (PLI)

The pollution load index (PLI) for all the samples is calculated as the methods developed by to asses the level of heavy metal pollution (Tomlinson *et al.*, 1980). The simple mathematical expression of PLI is expressed as:

$$PLI = \sqrt[5]{CF_{Fe} \times CF_{Cu} \times CF_{Cd} \times CF_{Pb} \times CF_{Zn}} \quad (3)$$

where CF is the contamination factor obtained by calculating the ratio of each metal's concentration to its background values. The PLI value >1 indicates a polluted condition and PLI <1 indicates no metal pollution existing (Tomlinson *et al.*, 1980). Obtained PLI values are between 0.26-0.60 and 0.33-0.99 with a mean of 0.40 and 0.62 for the NE and SW, respectively (Figure 6). Among these 15 stations, higher PLI values such as 0.60 and 0.99 were obtained at station 5 and 2, which clearly showed values <1 that is close to the background level, i.e., there is no metal contamination around the study area.

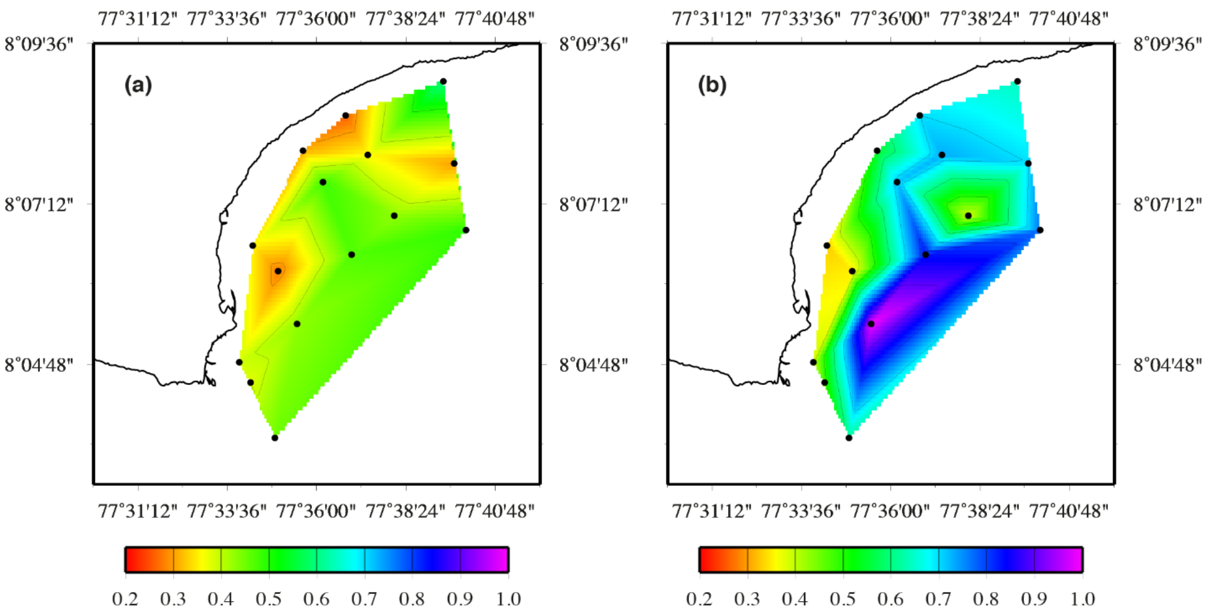


**Fig. 6. Contour map shows the spatial distribution of the Pollution load index during (a) NE monsoon and (b) southwest monsoon**

## Ecological Risk Index

The ecological risk index was first proposed by Hakanson (1980) to assess the risk of aquatic pollution in sediments by the effect of trace metals. According to the toxicity of metals, the comprehensive methods were carried out and are widely used by Yi *et al.* (2011) and Wang *et al.* (2013). Based on Hakanson (1980) approach, the toxic response factors for Cd, Cu, Pb, and Zn are calculated followed by the toxic response values of 30, 5, 5, and 1, respectively (Xu *et al.*, 2008).

$$E_r^i = \frac{C^i}{C_o^i} \times T_r^i \quad (4)$$

$$RI = \sum_{i=1}^{5} E_r^i \quad (5)$$

where $E_r^i$ is the potential ecological risk index; $C^i$ and $C_o^i$ are the measured and background value of the specific metal concentrations in the sediment. $T_r^i$ is the metal's toxic response factor. The following terminology was used to categorize the $E_r$ and RI values (Table 4) suggested by Hakanson (1980) and are widely used by many authors (Zhu *et al.*, 2011; Wang *et al.*, 2013).

**Table 4. Ecological risk assessment of trace metals in Kanyakumari coast**

| $E_r^i$ | Ecological risk of single metal | RI | Ecological risk of environment |
|---|---|---|---|
| $E_r^i$<40 | Low risk | RI<150 | Low risk |
| 40≤ $E_r^i$ <80 | Moderate risk | 150≤RI<300 | Moderate risk |
| 80≤ $E_r^i$ <160 | Considerable risk | 300≤RI<600 | Considerable risk |
| 160≤ $E_r^i$ <320 | High risk | RI≥600 | Very high risk |
| $E_r^i$ ≥320 | Very high | | |

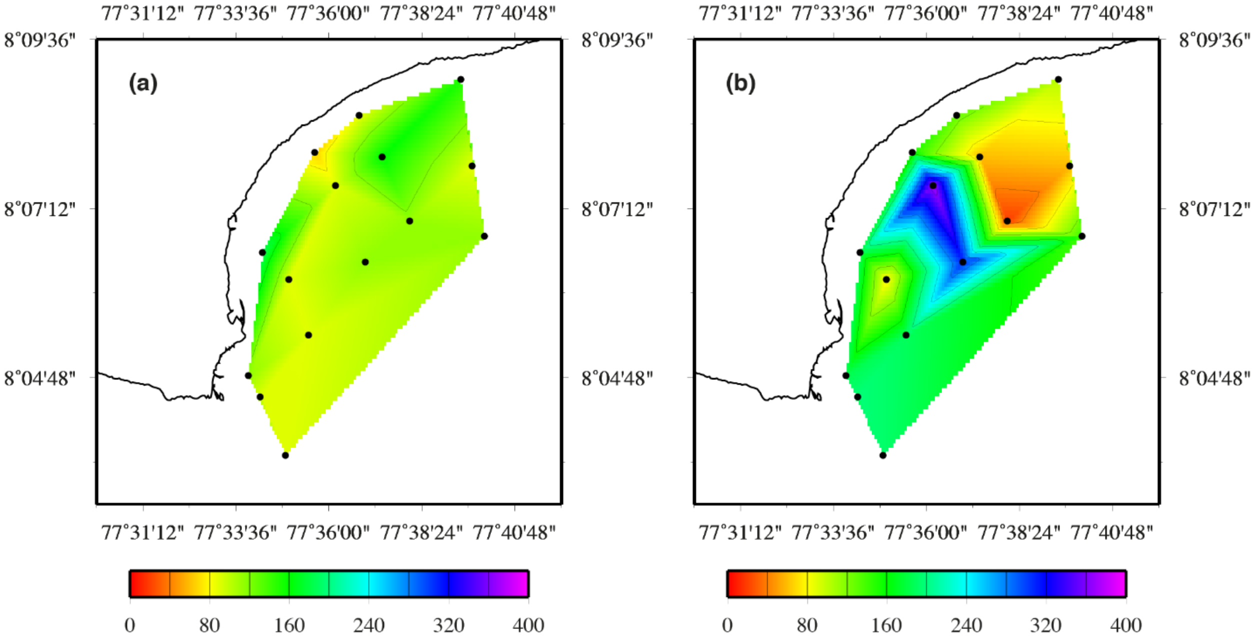


**Fig. 7. Contour map shows the spatial distribution of Ecological risk index during (a) NE monsoon and (b) southwest monsoon**

The Kanyakumari coastal sediments reflect the two variable environmental risk from the trace metal concentrations. The potential ecological risk index of Cd, Cu, Pb, Zn from 15 stations were ranged from 64.96-111.48, which indicated that environmental risk from the north of the study area is considerably low in NE monsoon (Fig. 7), whereas in SW monsoon season, environmental risk index (RI) showed a moderate risk that could be from the Pazhar river discharge and it diluted the risk from station 4 and 5. Overall, the risk index showed a moderate risk during SW monsoon and low risk in NE monsoon season. Ecological risk index of Cd possessed relatively high ecological hazards, with its average values of 105.88 and 154.59 during SW and NE monsoon. For other metals (Cu, Pb, and Zn), the potential ecological risk indices were considerably low compared to the Cd.

## Controlling Factors

Various physical processes influence the distribution of trace metals in sediments (Monteiro and Roychoudhury, 2005). In the present study, the influence of tides, wave, currents, and wind pattern on the spatial and seasonal distribution of trace metals in sediment were studied. The observed tides in the study area are shown in Figure 8. Maximum of 1.15 m tidal range in the study area was observed during NE monsoon season (Gurumoorthi *et al*., 2015). Tidal range in the Bay of Bengal and Arabian Sea is increasing from south to north due to a broadening of the continental shelf (Kankara *et al*., 2013; Unnikrishanan, 2010; Kunte *et al*., 2000).

The currents along the study were dominated by tides (Shetye *et al*., 1991; Unnikrishnan *et al*., 1999). The magnitudes of maximum current speed were observed 0.53 m/s during the SW monsoon season with an average of 0.22 m/s at L 1, which is higher than an NE monsoon season (Figs. 9 and 10). During the NE monsoon season, surface currents along east Indian coast flows in SW direction from Palk Bay to GoM (Rao *et al*., 2011) and SW monsoon currents flow towards GoM to PB due to the prevailing wind direction (Fig. 11).

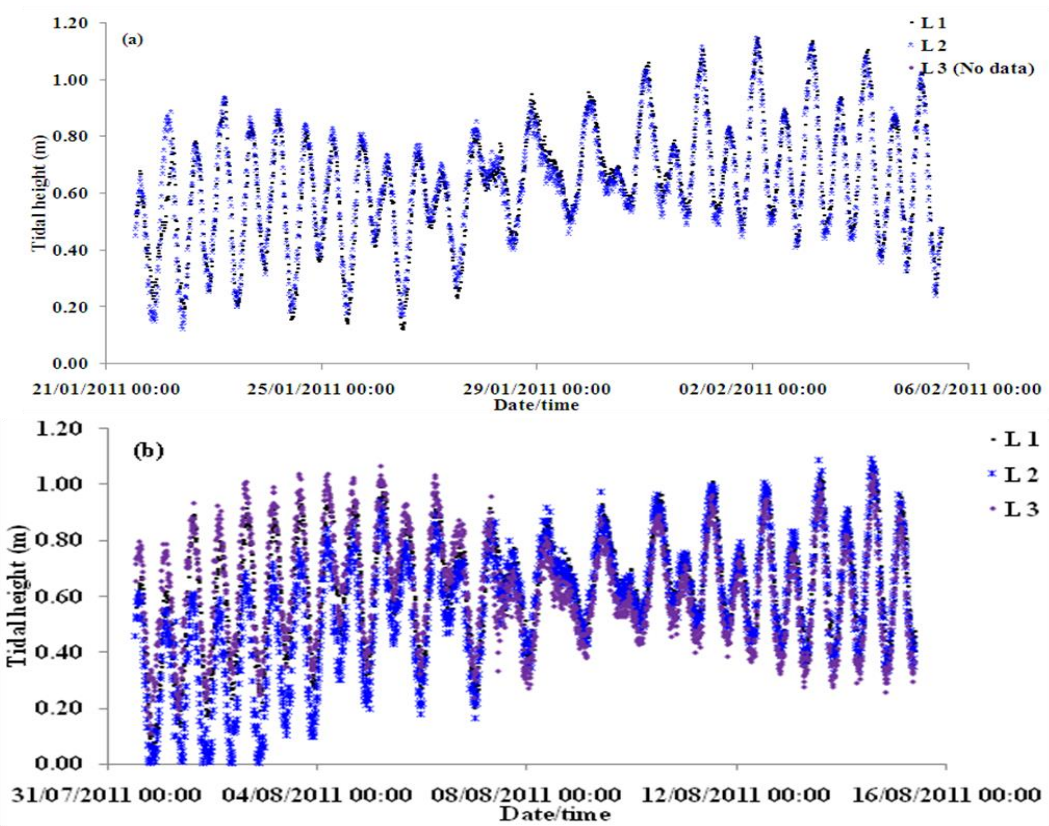


**Fig. 8. Tidal level variation along the study area during (a) NE monsoon and (b) SW monsoon season**

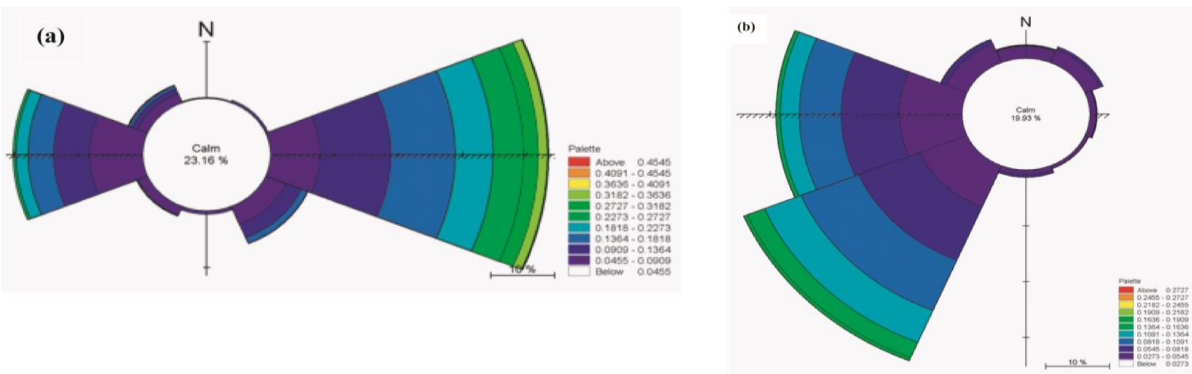


**Fig. 9. Current speed and direction during NE monsoon season in locations (a) L1, and (b) L2**

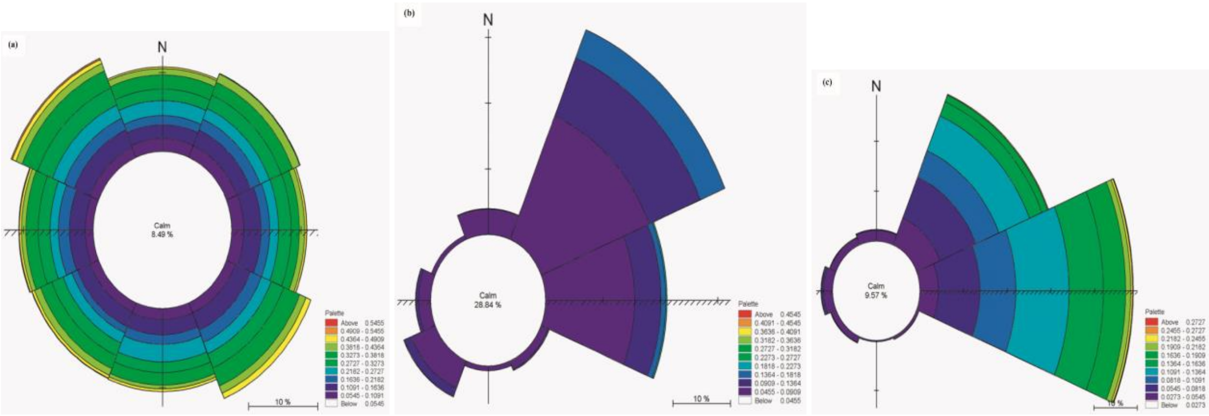


**Fig. 10. Current speed and direction during SW monsoon season in locations (a) L1, (b) L2, (c) L3**

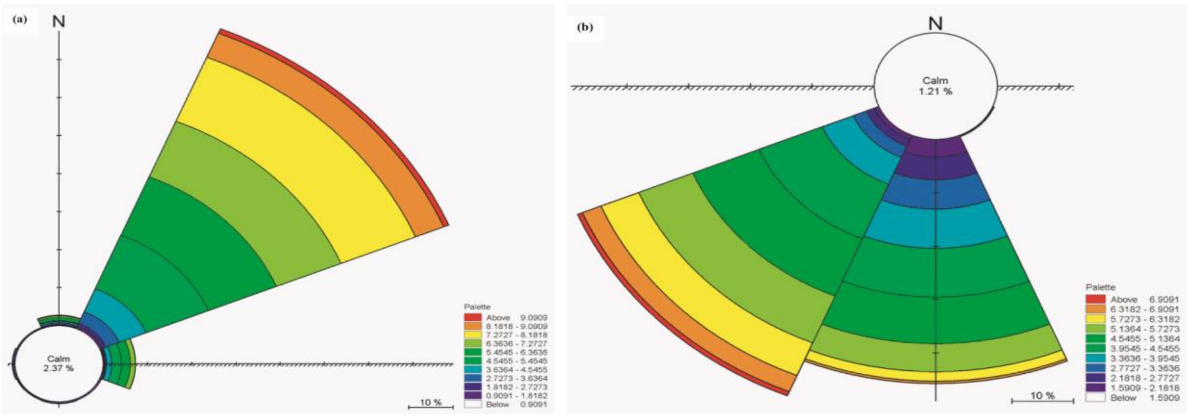


**Fig. 11. Measured wind speed and wind direction during NE (a) and SW (b) monsoon season**

The occurrence of a higher amount of trace metal contamination is derived from the West India coastal current (WICC), which carries the trace metal from remote areas. The textural distribution and their trace metal contamination of the sediments along the Kanyakumari transect revealed that they were mainly dependent on the hydrodynamic nature of the coastal region. The littoral sediments and their textural composition are well studied and may depend on waves, winds, and longshore currents (Kaliraj *et al*., 2013).

The moderate to high wave energy (2.12 to 3.83 kJ/km$^2$) conditions during NE to SW monsoon, the study area, is replenished with valuable deposits of heavy minerals, thus it is an enriched zone of placer mineral deposits (Saravanan and Chandrasekar, 2010). The seasonal distribution of trace metals showed a significant variation in their concentration with respect to prevailing tides, waves, and currents. The concentration level of surface sediment recorded lower concentrations of trace metals in NE monsoon, whereas higher concentrations were recorded in the SW monsoon period.

## CONCLUSION

This study examined the presence of trace metals varying spatially and seasonally in surface sediments during NE and SW monsoon season 2011. The distribution of trace elements in coastal sediments revealed the state of environmental/marine ecological and geochemical pollution. Metal enrichment observed in SW monsoon season from west coast of India is due to the remote discharges. The distributions of texture size and total organic carbon were influenced by the existing hydrodynamic pattern, especially monsoon currents. The relationship between those two parameters allowed to understand the finer particle to trap more organic pollutants due to their large specific area.

Our results revealed the spatial distribution of trace metals in sediments indicate the increase from near shore to the offshore region during both NE and SW monsoon due to remotely anthropogenic activities, especially marine-based activities. Moreover, the higher average concentration of trace elements found in SW monsoon season, which results from the development of industrialization, is more along the west coast of India. It is also confirmed that deposition of trace metals depends on the monsoonal variability and these metals are concentrated more from the west coast than the east coast of India.

Therefore, the potential source and seasonal variation of the trace metal concentration is the result of the geomorphology of the coast which, associated by reversal winds with northeast and southwest monsoon, change the oceanographic phenomena (tide, waves, and monsoonal circulation). From the results of environmental risk assessment, anthropogenic sources place an input of the trace metal along the Kanyakumari coast and there is a low metal pollution but Cadmium contributes the moderately polluted. The ecological index concluded a low to moderate pollution (NE to SW); this might impose less impact on the marine ecosystem. The present study sturdily recommends that continuous monitoring of trace metal pollution should be carried out to maintain the GoM, free from the trace metal pollution to form ever blue marine ecosystem.

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